APPLICATION

OF

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FOR

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ON

ACOUSTIC ABSORPTION RADIATION SENSING IN SiC

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ACOUSTIC ABSORPTION RADIATION SENSING IN SiC

RELATED APPLICATION

[0001] This is a continuation-in-part of application Serial No. 09/906,441, filed July 16, 2001 by the same inventor for ACOUSTIC ABSORPTION ELECTROMAGNETIC RADIATION SENSING WITH SINGLE CRYSTAL SiC.

BACKGROUND OF THE INVENTION

[0002] Field of the Invention

[0003] This invention relates to the use of SiC for electromagnetic radiation sensing and resistance control.

[0004] Description of the Related Art

[0005] Acoustic absorption, bandgap absorption and impurity absorption refer to three different radiation absorption mechanisms. Acoustic absorption results from increasing lattice vibration under radiation exposure. This is a desirable absorption mechanism when detection is sought over a broad range of wavelengths, since it causes the resistance of a SiC chip to increase approximately linearly with the irradiating energy over an appreciable wavelength range. SiC absorbs heat throughout its volume, not just along its surface, and therefore has a high thermal capacity for absorbing high laser doses and other applications. While it would be desirable to employ SiC for detecting infrared (IR) radiation and other lower wavelength radiation, acoustic absorption has

not been observed in SiC for wavelengths below about 10 micrometers, thus eliminating part of the IR band along with shorter wavelengths.

[0006] Bandgap absorption occurs at a specific wavelength corresponding to a material's bandgap energy (the energy differential between its conductance and valence bands). SiC can occur in more than 70 different polytypes, each of which has its own distinguishing bandgap energy as measured parallel to the c-axis of a single crystal. The cubic crystalline form of SiC (referred to as 3C-SiC or β-SiC) has the lowest energy bandgap (approximately 2.3 eV), with the longest corresponding wavelength (approximately 0.55 microns) of all SiC crystal structures and polytypes, but this is yellow/green light entirely outside the IR range. The bandgaps of all other SiC crystal structures and polytypes are higher in energy with shorter wavelengths, making SiC unsuitable for bandgap absorption detection of IR.

[0007] With impurity absorption, a dopant is introduced into a host material and radiation is detected at the energy differential between the host and dopant conductive band energy levels (for an n-type dopant) or valence band energy levels (for a p-type dopant). The resistance of a chip of host material drops exponentially with the radiation energy at the specific wavelength corresponding to the impurity absorption energy but not at other wavelengths, resulting only in a discrete detectable wavelength. Impurity absorption has been observed with SiC in the IR range (Air Force Materials Laboratory, "Silicon Carbide Absorption", Hughes Aircraft Company Electronic Properties Information Center, pages 9-16), but only at specific wavelengths corresponding to particular impurities. No IR absorption mechanism over a broad band has been discovered.

SUMMARY OF THE INVENTION

[0008] The present invention achieves electromagnetic radiation detection at wavelengths shorter than about 10 micrometers, with a detector that has both a high thermal capacity and an output that varies approximately linearly with the radiating energy, by utilizing a previously unknown acoustic absorption mechanism for SiC. By using SiC with a thickness of at least 200 micrometers, and preferably greater than about 400 micrometers, it has been discovered that an acoustic absorption mechanism exists that can be used to detect radiation at less than 10 micrometers. The absorption increases with increasing thickness, up to a thickness of about 2,000 micrometers. The invention is particularly useful for IR detection, and can be adapted for narrow band detection by the use of an appropriate spectral filter. The absorption can be enhanced with the use of a SiC body having an approximately uniform thickness with a major surface that is approximately flat for receiving the IR, and a non-dopant impurity level low enough that it does not interfere with the achievement of a single crystalline structure for the SiC.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] These and other features and advantages of the invention will be apparent to those skilled in the art from the following detailed description of preferred embodiments, taken together with the accompanying drawing, in which:

[0010] FIG. 1 is a simplified schematic diagram of the invention used to sense the energy of an IR laser beam.

DETAILED DESCRIPTION OF THE INVENTION

[0011] The invention employs SiC as a radiation sensor at wavelengths below about 10 micrometers, and is particu-

larly valuable for IR sensing within this range. Applications include the sensing of radiation power or energy emitted from a radiation source such as a laser, contactless sensing of the temperature of other bodies which are heated by IR radiation, and controlled varistors for electrical circuits.

[0012] Whereas no acoustic absorption has been observed for SiC at wavelengths below about 10 micrometers, applicant has discovered that a useful acoustic absorption mechanism can be obtained from SiC if it has a single crystal structure and its thickness is at least about 200 micrometers. While there may be some acoustic absorption with thinner samples, the amount is so small that it has not previously been observed. IR radiation absorbed via acoustic absorption is converted directly into heat energy and causes the resistance of the SiC to increase roughly linearly with the IR energy, as opposed to impurity absorption which causes the SiC resistance to drop.

[0013] The amount of acoustic absorption progressively increases as the SiC thickness increases above the threshold of about 200 micrometers, and approaches a maximum absorption level at about 2,000 micrometers thickness. A preferred thickness range is about 400-2,000 micrometers. Thicker bodies of SiC could also be used, but they would not materially improve the acoustic absorption and would be more bulky.

[0014] Among the IR applications for SiC are beam energy and power sensing, for example to sense the energy or power of an IR laser beam or focused radiation from an IR lamp. SiC is particularly advantageous for these applications, since it can absorb very high energy doses over very short time periods without being damaged. Thus, it can be used for energy/power sensing of emitted energy from medium power (powers in the range of 10 watts-300 watts) and many high power (powers in excess of 300

watts) IR lasers, with the SiC sensing surface exposed to the entire output energy without fan or water cooling, withstanding temperatures in excess of 1300 degrees C. The superior high power density handling capability of

5   SiC permits the use of smaller volume SiC sensor elements, relative to those now employed, for a given power level. Furthermore, the smaller size of SiC sensor elements facilitates self-cooling after absorbing a laser pulse more rapidly than other materials used to sense IR

10 radiation. The high thermal conductivity of SiC provides for a rapid distribution of absorbed energy over the entire sensor volume, which substantially reduces the susceptibility of the sensor element to damage and thermal shock from large lateral temperature gradients that may

15 be induced when a small area of a sensor element is exposed to a high energy laser beam. The low piezoelectric coefficient of SiC (relative to pyroelectric materials), coupled with its high thermal conductivity (higher than Cu at room temperature), inhibits the generation of large

20 piezoelectric signals in the sensor from focused laser beams. In general, the favorable thermal shock tolerance of SiC allows it to absorb laser pulses containing high energy, and to be used for relatively long exposures to IR radiation at high energy/power intensities in a small

25 volume and area sensor.

[0015] The use of SiC as an IR radiation energy sensor is illustrated in FIG. 1. An IR radiation source such as laser 2 emits an IR beam 4 within a specified waveband (defined herein to include both the case of a single

30 wavelength and multiple wavelengths). An SiC sensor body 6 is placed in the beam path, preferably receiving the entire beam. An optional spectral filter 8 of standard construction may be placed in the beam path prior to the sensor body 6 if it is desired to restrict the radiation

35 reaching the sensor to a single wavelength or other nar-

row waveband. For example, if it is desired to detect radiation at only a specified wavelength, the filter 8 would be tuned to that wavelength and block radiation at other wavelengths.

5   **0016]** A constant voltage source 10 applies a constant voltage across the SiC body, while a current sensor 12 senses the resulting current through the SiC. The SiC temperature changes in response to the received IR radiation, with a corresponding resistance change that depends

10   upon the radiation wavelength(s), intensity and exposure time. Since there is a fixed relationship between the SiC temperature and its resistance for a given sample, the SiC temperature can be determined as a function of the current flowing through it, as sensed by the current

15   meter 12. There is also a direct correspondence between the IR radiation energy absorbed by the SiC and its temperature. Accordingly, the current response of the SiC will vary in a one-to-one relationship with the IR beam energy. Calibrating the current meter 12 to the SiC's

20   resistance temperature coefficient, and also to cancel the effect of any current-induced heating, thus allows for a direct readout of the IR beam energy.

  [0017] Rather than applying a constant voltage and sensing the resulting SiC current as in FIG. 1, a constant

25   current could be applied with the output circuit and the resulting SiC voltage response sensed. Differentiating the instantaneous rate at which the SiC resistance, and thus its temperature, changes can provide a direct indication of the instantaneous power in the IR beam.

30   **[0018]** The thickness of the SiC body 6 is preferably at least approximately uniform, with a major surface facing the beam 4 that is at least approximately flat. This provides for an acoustic absorption that is at least approximately uniform over a cross-section of the SiC body

35   parallel to its major flat surface. Absolute uniform

thickness and surface flatness is not required, and in fact roughening the forward surface somewhat can vary the direction the IR travels through the SiC from the roughened areas. This would tend to increase the effective IR path length through the SiC, and thus also increase its acoustic absorption (at least for SiC thicknesses less than about 2,000 micrometers).

[0019] The SiC body can be doped, but the purest acoustic absorption response is obtained when it is intrinsic. While the primary immediate application of the invention is considered to be in the IR range, it is also applicable to lower wavelengths, in the visible through ultraviolet (UV) regions.

[0020] The amount of acoustic absorption is not affected by the presence of Group III or V dopants, as long as the dopant concentrations are not excessive. However, the presence of non-dopant impurities changes the crystal structure, with increasing concentrations of non-dopant impurities making it more and more difficult to achieve a desirable single crystal structure. Such changes in crystal structure would tend to change the level of acoustic absorption in ways that are not presently predictable, thus making the accuracy of the sensor less reliable.

[0021] The invention produces a very stable and reproducible resistance vs temperature characteristic, and can withstand both absolute temperatures of at least 1400°C and very rapid temperature ramping without the need for fan or water cooling. It is robust and not easily damaged, maintains calibration well, and offers improvements in the ability to withstand high IR energy/power intensities, exposure times and thermal shock. Small SiC devices can be used because of their favorable high power density handling capabilities, without being subject to

large piezoelectric signals that can be induced in other materials by focused laser pulses.

[0022] Other radiation absorbent applications for SiC, such as contactless temperature sensing and varistors, as well as a preferred technique for mounting the SiC body in a mounting structure having an AlN substrate with a W, WC or W_2C mounting layer, are described in U.S. Patent No. 6,239,432, issued May 29, 2001 to the present inventor, the contents of which are incorporated herein.

[0023] While several illustrative embodiments of the invention have been shown and described, numerous variations and alternate embodiments will occur to those skilled in the art. Such variations and alternate embodiments are contemplated, and can be made without departing from the spirit and scope of the invention as defined in the appended claims.